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Second Quarterly Technical Report

INVESTIGATION OF LOW TEMPERATURE
MULTILEVEL DIELECTRICS FOR APPLICATION
FOR RADIATION TOLERANT, SUBMICRON-SCALED
IC TECHNOLOGY

Period Covered: 1 April 1989 to 30 June 1989

RTI Project No. 415U-3627

STRATEGIC DEFENSE INITIATIVE ORGANIZATION
Innovative Science and Technology Office

Office of Naval Research
ONR Contract No. N-00014-86-C-0421

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89 12 26 171

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SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified			1b. RESTRICTIVE MARKINGS NONE	
2a. SECURITY CLASSIFICATION AUTHORITY ---			3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release unlimited distribution	
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE ---				
4. PERFORMING ORGANIZATION REPORT NUMBER(S) 83B-3627			5. MONITORING ORGANIZATION REPORT NUMBER(S) Office of Naval Research	
6a. NAME OF PERFORMING ORGANIZATION Research Triangle Institute		6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION Office of Naval Research	
6c. ADDRESS (City, State, and ZIP Code) P.O. Box 12194 Research Triangle Park, NC 27709			7b. ADDRESS (City, State, and ZIP Code) 800 N. Quincy St. Arlington, VA 22217-5000	
8a. NAME OF FUNDING / SPONSORING ORGANIZATION SDIO/IST		8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER N-00014-86-C-0421	
8c. ADDRESS (City, State, and ZIP Code) SDIO/T/IS Pentagon Washington, DC 20301-7100			10. SOURCE OF FUNDING NUMBERS	
			PROGRAM ELEMENT NO.	PROJECT NO.
11. TITLE (Include Security Classification) Investigation of Low-Temperature, Multilevel Dielectrics for Application for Radiation Tolerant, Submicron-Scaled IC Technology (Unclassified)				
12. PERSONAL AUTHOR(S) R.J. Markunas et al.				
13a. TYPE OF REPORT Quarterly		13b. TIME COVERED FROM 4/1/89 TO 6/30/89		14. DATE OF REPORT (Year, Month, Day) 7/15/89
15. PAGE COUNT				
16. SUPPLEMENTARY NOTATION				
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number) Silicon Dioxide, Oxynitrides, Plasma CVD	
FIELD	GROUP	SUB-GROUP		
19. ABSTRACT (Continue on reverse if necessary and identify by block number) The following report details the progress on ONR contract number N-00014-86-0421 during the period from April 1, 1989 to June 30, 1989. This program entails a joint effort between Research Triangle Institute and North Carolina State University. During this quarter work has proceeded in mapping out the nitride deposition parameter space. The new ultra high purity reactor is on line and in use. Nitride results show a 2 order of magnitude improvement.				
20. DISTRIBUTION / AVAILABILITY OF ABSTRACT <input checked="" type="checkbox"/> UNCLASSIFIED/UNLIMITED <input type="checkbox"/> SAME AS RPT. <input type="checkbox"/> OTIC USERS			21. ABSTRACT SECURITY CLASSIFICATION	
22a. NAME OF RESPONSIBLE INDIVIDUAL R.J. Markunas			22b. TELEPHONE (Include Area Code) 919-541-6153	22c. OFFICE SYMBOL

DD FORM 1473, 84 MAR

83 APR edition may be used until exhausted.
All other editions are obsolete.SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

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1.0 INTRODUCTION

The following report details the progress on ONR Contract Number N-00014-86-0421 during the period from 1 April 1989 to 30 June 1989. This program entails a joint effort between Research Triangle Institute and North Carolina State University. Funding is being provided by the Innovative Science and Technology Office of the Strategic Defense Initiative.

During this quarter work has proceeded in mapping out the nitride deposition parameter space. This work is described in section 2.0. The new ultra-high purity reactor is on line and in use. Nitride results showing a 2 order of magnitude improvement over results from the original reactor are given. This work is described in section 3.0. Section 4.0 includes the summary and preview.

2.0 NITRIDE DEPOSITION WORK

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→ A great deal of effort has been put into characterization of the remote plasma-enhanced nitride deposition process using N_2 as the nitrogen source. The data base ~~listing in Appendix A~~ includes deposition conditions and characterizations of the deposited films. The deposition variables include temperature, pressure, and gas flow rates. The characterizations include deposition rate, etch rate, refractive index (from ellipsometry), dielectric constant, infrared data, flatband shift, and hydrogen content. This data base allows correlation of data according to any combination of parameters in the data base. This function can be used to verify the possibility of improbability of various suspected correlations. This capability is illustrated in Figure 1, "Growth rate vs. Silane Flow Rate". Note the parameters listed under the title.

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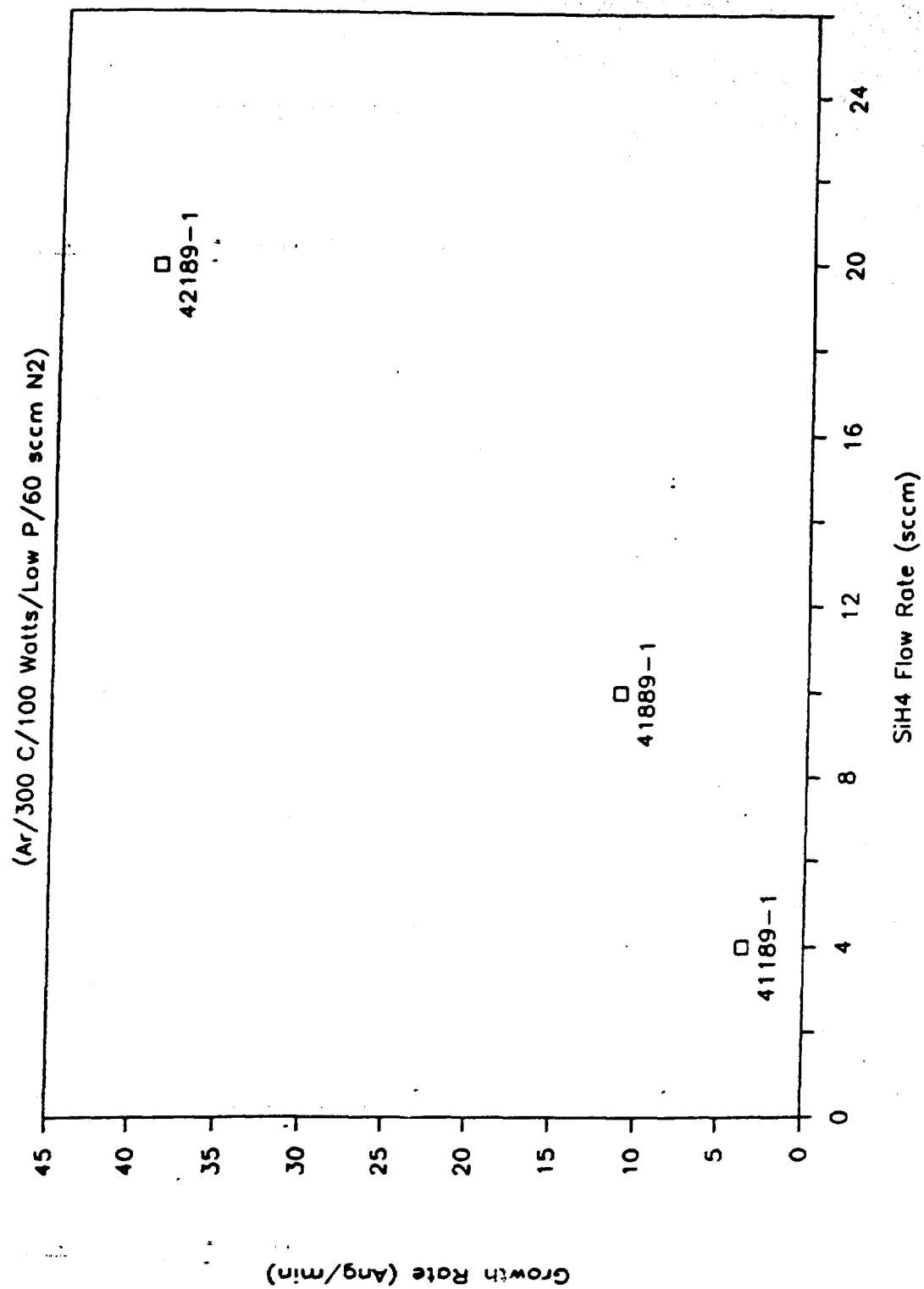


FIGURE 1: Growth rate vs. SiH₄ rate.

3.0 NEW ULTRA-HIGH PURITY REMOTE PLASMA DEPOSITION SYSTEM

A new ultra-high purity deposition system is now on line and operating at RTI. This reactor takes advantage of the insights we have gained into the oxide and nitride deposition processes. The reactor has an all quartz deposition region for high purity, and a long flow tube type design to minimize eddie current flows. The all-quartz construction of the reaction zone allows us to use external heaters to heat the sample, which greatly simplifies the internal construction of the reactor and eliminates many sources of contamination. The reaction zone is heated with infra-red lamps. This radiation should couple very well into any water-related byproducts and help to drive them off of the reactor walls so they can be transported out of the reaction zone. The gas delivery lines are very short to minimize contamination from the lines, and each gas will be filtered at its injection point with a .05 micron filter. All-metal sealed leak valves are used for flow control so that the gas lines are entirely UHV compatible and bakeable. The system provides much latitude for adjustment of sample position and plasma region position. We believe this system will allow us to make major strides in the development of high-quality, highly reliable dielectrics.

Already the new system is proving its viability in the area of nitride deposition. The charge to breakdown data shown in Figure 2 is from a nitride deposited at 300 °C in the new system. This nitride film passed a total charge of over 400 C/cm² before breaking down. The total voltage shift was less than 0.1 Volt. The best nitride films

cut of the original reactor had total charge to breakdown values of 1 C/cm^2 . This exciting new result we attribute to the overall improved purity in the new reactor.

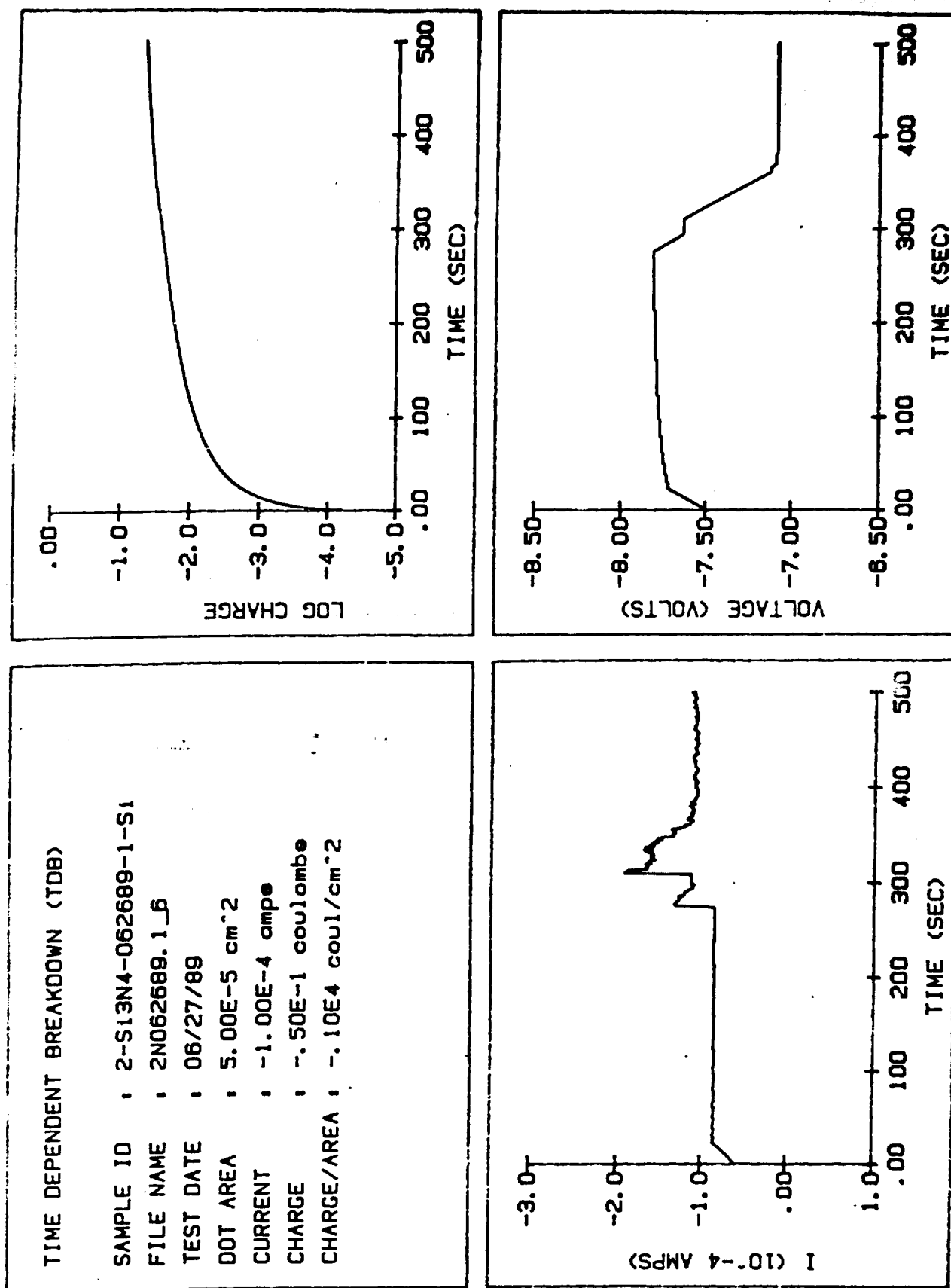


FIGURE 2: Time dependent breakdown measurement for Si₃N₄ film (~ 10 nm thick) deposited at 300 °C using the new ultra-high purity reactor.

4.0 SUMMARY AND PREVIEW

During this quarter the nitride deposition process parameter space has been intensively investigated. The data has been entered into a data base for convenient evaluation. Possible correlations of deposition parameters with material characteristics are being evaluated.

The new ultra-high purity deposition system has been brought on line and is being exercised. This system has already shown the capability of improving the quality of the deposited materials in the nitride deposition area. A Si_3N_4 film has been deposited which passed 400 C/cm^2 before breaking down. This result is a 2 order of magnitude improvement over results obtained in the original system.

During the next quarter we will report additional results from deposition studies conducted using the new ultra-high purity reactor. These studies will include both oxide and nitride depositions.

APPENDIX A

SILICON NITRIDE DEPOSITION PROCESS OPTIMIZATION

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Sample	Growth Conditions			Plasma Feed			Ring Feed			Film Thickness (Å)	
	Temp. (C)	Power (Watts)	Press. (Torr)	Ar (sccm)	He	N2	SiH4 (sccm)	N2	H2		Ar/He
32889-2	300	30	Low P	400			10	60			491.4
32989-2	300	30	Low P	400			10	60	100		585.0
33189-2	300	30	Low P	400			4	60			
40389-2	300	30	0.30	400			10	60			1598.4
40689-2	300	30	0.30	400			2	60			320.0
40789-1	300	30	0.30	400			4	60		100	1327.0
40789-2	300	30	Low P	400			4	60	100		470.0
41089-1	300	30	Low P	400			2	60			too thin
41189-1	300	100	Low P	400			4	60			876.0
41189-2	350	30	Low P	400			4	60			542.0
41289-1	300	30	Low P	400			4	60			645.0
41289-2	300	100	Low P	400			4	30			678.3
41389-1	300	30	0.30	400			4	60			770.0
41389-2	300	30	0.20	400			4	60			1026.0
41489-1	300	30	Low P	400			4	30			461.6
41789-1	300	30	Low P	400			4	60			510.0
41889-1	300	100	Low P	400			10	60			1350.0
41989-1	300	100	Low P	400			10	60			2200.0
42189-1	300	100	Low P	400			20	60			2340.0
42189-2	300	100	0.30	400			4	60			970.0
42489-1	300	100	Low P	400			10	100			2000.0
42489-2	300	100	Low P	400			10	100			2750.0
42689-2	300	100	Low P	400			10	20			2150.0
50289-1	300	30	0.07	400		20	4				430.0
50289-2	300	30	0.07	400			4	20			600.0
50389-1	300	30	0.07	400		20	10				653.0
50389-2	300	30	0.07	400			10	20			730.0

SILICON NITRIDE DEPOSITION PROCESS OPTIMIZATION

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Sample	Growth Conditions			Plasma Feed		Ring Feed				Film Thickness (Å)
	Temp. (C)	Power (Watts)	Press. (Torr)	Ar (sccm)	He	N2	SiH4 (sccm)	H2	Ar/He	
50389-3	300	10	0.07	400		20	4			431.0
50489-1	300	30	0.10		500	10	10			750.0
50589-1	300	30	0.10		500		10			565.0
50589-2	300	30	0.10		500	10	4			250.0
50589-3	300	30	0.20		500	40	10			605.0
50889-1	300	30	0.10		500	40	10			410.0
50889-2	300	30	0.10		200	40	10			230.0
50889-3	300	30	0.10		100	40	10			100.0
50989-1	300	30	0.30		200	40	4			160.0
51089-1	300	30	Low P		200	40	10			0.0
51089-2	300	30	Low P		400		10	5		555.0
51089-3	300	30	Low P		400		10	20		315.0
51189-1	300	30	Low P		400		10	40		307.5
51189-2	400	30	Low P		200		10	40		464.0
51189-3	400	30	Low P		300		10	40		225.0
51289-1	400	30	Low P		300		4	40		
51289-2	400	30	Low P		200	40	4			175.0
51589-1	350	100	Low P		200		10	100		558.0
51589-2	350	100	Low P		200	100	10			567.0
51589-3	350	200	Low P		200		10	100		588.0
51689-1	350	200	Low P		200		10	100		913.0
51689-2	350	200	Low P		200	100	10			570.0
51689-3	350	200	Low P		200	100	4	100		519.0
					500		10	100		820.5

SILICON NITRIDE DEPOSITION PROCESS OPTIMIZATION

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Sample	Growth Conditions		Plasma Feed		Ring Feed		Film Thickness (A)
	Temp. (C)	Power (Watts)	Press. (Torr)	Ar	He	N2	
51789-1	350	200	Low P		500	100	680.0
51789-2	400	200	Low P		200		627.0
51789-3	400	200	0.08	200		100	
51889-1	300	200	0.08	200		100	473.0
51889-2	300	200	0.08	500		40	533.0
51889-3	300	200	0.08	500		100	1014.0
51989-1	400	200	0.08	300		100	
51989-2	400	200	0.07	300		100	
51989-3	400	200	0.08	300		100	

SILICON NITRIDE DEPOSITION PROCESS OPTIMIZATION

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Sample	Growth		Etch		Optical Thickness (A)	Refract. Index (n)	Concentration	
	Time (min)	Rate (A/min)	Thickness (A)	Time (sec)			[Si-H] cm-3	[N-H]
32889-2	45	10.92	96.5	5	537.0	1.734		1.94E+22
32889-2	90	6.50	77.5	5	606.0	1.784		2.16E+22
33189-2	120	0.00		5	442.5	1.802		
40389-2	120	13.32	80.0	5	1455.5	1.812	1.00E+21	1.33E+22
40689-2	180	1.78	235.0	10	239.0	2.000		
40789-1	180	7.37	1150.0		1342.5	1.668		1.09E+22
40789-2	210	2.24	455.0	5	567.3	1.713		1.57E+22
41089-1	240	0.00		5	280.0	2.000		
41189-1	240	3.65	57.5	120	859.3	1.899		5.63E+21
41189-2	180	3.01	75.0	30	663.0	1.819		5.50E+21
41289-1	180	3.58	228.0	30	608.5	1.809		6.17E+21
41289-2	180	3.77	130.0	180	735.0	1.896		5.16E+21
41389-1	180	4.28	113.3	5	928.0	1.680		9.46E+21
41389-2	180	5.70	511.6	5	867.0	1.702		7.08E+21
41489-1	180	2.56	461.0	5	662.0	1.820		1.80E+22
41789-1	180	2.83	45.0	10	631.0	1.785		2.50E+22
41889-1	120	11.25	322.5	30	2342.0	2.000		
41889-1		ERR		5				
42189-1	60	39.00	30.0	5	1904.5	2.000		5.32E+21
42189-2	180	5.39	450.0	5	882.0	1.727		1.13E+22
42489-1	120	16.67	40.0	5	1715.7	2.000		4.47E+21
42489-2	120	22.92		5				6.22E+21
42689-2	128	16.80	60.0	10	1766.0	2.000		
50289-1	180	2.39		5	670.0	1.808		
50289-2	180	3.33		5	664.0	1.747		
50389-1	60	10.88		5	758.0	1.743		
50389-2	60	12.17		5				

SILICON NITRIDE DEPOSITION PROCESS OPTIMIZATION

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Sample	Growth		Etch		Rate		Refract.		Concentration	
	Time (min)	Rate (Å/min)	Thickness (Å)	Time (sec)	Rate (Å/sec)	Index (n)	Thickness (Å)	Index (n)	[Si-H] cm-3	[N-H]
50389-3	180	2.39		5	0.00		474.0	1.790		
50489-1	120	6.25		5	0.00		793.0	1.803		
50589-1	90	6.28		5	0.00		584.5	1.801		
50589-2	180	1.39			ERR		341.0	2.000		
50589-3	120	5.04			ERR		548.0	1.811		
50889-1	90	4.56			ERR		417.0	1.794		
50889-2	60	3.83			ERR		245.0	2.000		
50889-3	60	1.67			ERR		156.0	2.000		
50989-1	180	0.89		5	0.00		250.0	2.000		
50989-2	90	0.00		5	0.00		30.0	2.000		
51089-1	90	6.17		5	0.00		607.0	1.830		
51089-2	60	5.25		5	0.00		304.0	2.000		
51089-3	60	5.13		5	0.00		280.0	2.000		
51189-1	90	5.16		5	0.00		464.0	1.826		
51189-2	60	3.75		5	0.00		233.0	2.000		
51189-3	180	0.00		5	0.00		188.0	2.000		
51289-1	210	0.83		5	0.00		245.0	2.000		
51289-2	120	4.65		5	0.00		558.0	1.845		
51589-1	90	6.30		5	0.00		567.0	1.867		
51589-2	90	6.53		5	0.00		588.0	1.860		
51589-3	180	5.07	360.8	120	3.01		913.0	1.867		
51689-1	90	6.33		5	0.00		570.0	1.880		
51689-2	210	2.47		5	0.00		519.0	1.926		
51689-3	90	9.12	283.0	20	14.15		800.5	1.857		

SILICON NITRIDE DEPOSITION PROCESS OPTIMIZATION

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Sample	Growth		Etch		Rate (A/sec)	Optical		Concentration	
	Time (min)	Rate (A/min)	Thickness (A)	Time (sec)		Thickness (A)	Refract. Index (n)	[Si-H] cm-3	[N-H]
51789-1	90	7.56		5	0.00	668.0	1.849		
51789-2	90	6.97		5	0.00	627.0	1.880		
51789-3	180	2.63	938.0	120	7.82	473.0	1.932		
51889-1	90	5.92			ERR	533.0	1.882		
51889-2	120	8.45	50.0	20	2.50				
51889-3	120	0.00			ERR				
51989-1	210	0.00			ERR				
51989-2	90	0.00			ERR				
51989-3	210	0.00			ERR				

SILICON NITRIDE DEPOSITION PROCESS OPTIMIZATION

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Sample	Accum. Cap. pF	Flat-Band Voltage Shift (V)	I-V Ledge (Log I)	Epsilon-R Si3N4
32889-2				0.00
32989-2				0.00
33189-2				0.00
40389-2	125.0	-3.15	1.0E-07	10.96
40689-2	124.2	-1.40	1.0E-07	2.18
40789-1	140.0	-1.15	5.0E-08	10.19
40789-2	350.0	-2.00	1.0E-07	9.02
41089-1	335.0	-2.25		0.00
41189-1	218.0	-2.60	1.0E-08	10.47
41189-2	140.0	-15.60	1.0E-09	4.16
41289-1	223.0	-1.95	1.0E-08	7.89
41289-2	102.1	-21.50	1.0E-09	3.80
41389-1	295.0	-1.15	1.0E-08	12.46
41389-2	234.7	-1.60	1.0E-07	13.21
41489-1	298.0	-1.25	1.0E-07	7.55
41789-1	220.0	-1.60	1.0E-08	6.15
41889-1	138.0	-2.05	1.0E-07	10.22
41989-1	103.0	-1.25	1.0E-08	12.43
42189-1	115.2	-1.30	1.0E-07	14.79
42189-2	255.0	-1.30	1.0E-07	13.57
42489-1	150.0	-1.75	1.0E-07	16.46
42489-2	120.0	-2.20	1.0E-07	18.10
42689-2			1.0E-07	0.00
50289-1			1.0E-07	0.00
50289-2	218.0	-2.10	1.0E-07	7.17
50389-1	300.0	-1.60	1.0E-07	10.75
50389-2	370.4	-1.35	1.0E-07	14.83

SILICON NITRIDE DEPOSITION PROCESS OPTIMIZATION

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Sample	Accum. Cap. pF	Flat-Band Voltage Shift (V)	I-V Ledge (Log I)	Epsilon-R Si3N4
50389-3	255.0	-1.72	1.0E-07	6.03
50489-1	127.0	-5.00	1.0E-09	5.22
50589-1	230.0	-6.30	1.0E-09	7.13
50589-2				0.00
50589-3				0.00
50889-1				0.00
50889-2				0.00
50889-3				0.00
50989-1	377.4	-3.10	5.0E-09	3.31
50989-2				0.00
51089-1			1.0E-08	0.00
51089-2	307.1	-5.55	5.0E-08	5.31
51089-3	292.7	-5.15	5.0E-09	4.94
51189-1	251.0	-1.90	2.0E-08	6.39
51189-2	467.0	-4.60	9.0E-11	5.76
51189-3	596.0	-5.30	9.0E-11	0.00
51289-1	469.0	-6.45	5.0E-07	4.50
51289-2	204.0	-9.60	3.0E-09	6.24
51589-1	195.3	-3.30	6.0E-08	6.07
51589-2	191.5	-3.08	6.0E-08	6.18
51589-3	133.0	-3.95	6.0E-08	6.66
51689-1	211.0	-3.45	8.0E-08	6.60
51689-2	202.0	-15.00	1.0E-06	5.75
51689-3	157.8	-3.00	1.0E-07	7.10

SILICON NITRIDE DEPOSITION PROCESS OPTIMIZATION

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Sample	Accum. Cap. pF	Flat-Band Voltage Shift (V)	I-V Ledge (Log I)	Epsilon-R Si3N4
51789-1				0.00
51789-2	195.0	-3.55	8.0E-08	6.71
51789-3	182.0	-13.00	5.0E-11	4.72
51889-1	206.0	-4.35	5.0E-08	6.02
51889-2				0.00
51889-3				0.00
51989-1				0.00
51989-2				0.00
51989-3				0.00